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Imaging spectropolarimetry with IBIS: evolution of a magnetic feature.

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Abstract. We present the results from observations of the solar atmosphere acquired at the Dunn Solar Telescope with the Interferometric Bidimensional Spectrometer (IBIS). Full Stokes profiles in the FeI 617.3 line and Stokes I in the CaII 854.2 were acquired with high spatial and spectral resolutions for more than one hour allowing us to study the evolution of a magnetic feature associated to AR11005. Here we search for possible correlations between photospheric and chromospheric events examining the magnetic flux density evolution and waves propagation in the solar atmosphere.

Key words. Photosphere – Chromosphere – Spectropolarimetry

1. Introduction

This work presents the first results obtained from recent observation of a magnetic features on the solar surface as acquired with the new spectropolarimetric mode of IBIS (Interferometric BIdimensional Spectrometer).

Recent observations, using both imaging and spectroscopic instruments, of photospheric magnetic structures revealed that the details of such structures are not forecast by current models (Louis et al., 2008). Apart from the necessity of new observations to confirm and corroborate these findings, several other issues on magnetic features on the solar surface remain unresolved. Here we list some of these issues on which the imaging spectropolarimetry observations can shed new light.

At present, the basic structure of sunspots is still debated. The most cited models are the so-called ”monolithic” model, which associates to the sunspot a flux tube with a uniform magnetic field; and the so-called ”spaghetti” model, which describes the sunspot as a collection of several magnetic flux tube bundles (Watanabe et al., 2009). The observable differences between these two models should reside in the physical details of the small bright intrusions in the spot umbra: the umbral dots.

The energy part which is not irradiated by the darker and cooler sunspot must be stored or dissipated elsewhere. The models predict that a preferred mode should be the onset of a horizontal plasma flow around the sunspot whose linear dimension should be comparable with that of the sunspot (Brickhouse & Labonte, 1988). As a matter of fact, the ”moat flow” around many magnetic features, has long since been associated to this process. Also this model suffers from several problems, and, in particular, fails to account for the magnetic feature flow which seems to depart from the sunspot

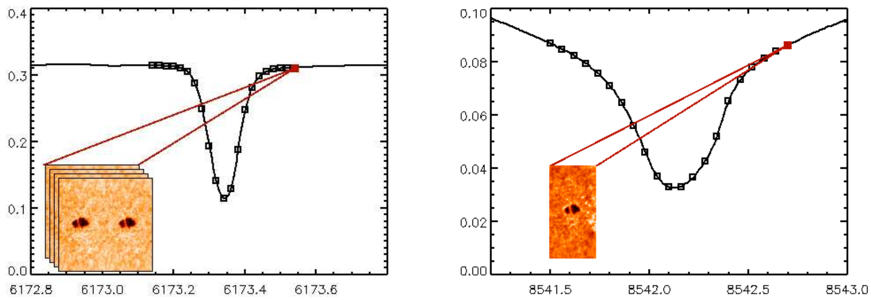

Fig. 1. Left panel: FeI 617.3 nm atlas line with the acquired wavelength positions overplotted. Right panel: same as above for the CaII 854.2 nm line. For each spectral point of the FeI line all the 6 polarization modulation states have been acquired, only the I state for the CaII.

and to move away sometimes faster than the mean plasma flow. Moreover, these "moving magnetic features" are evidently connected to the sunspot decay process, even if their role is still unclear.

Notwithstanding years of theoretical and observational efforts, the question: *"How much efficient are the convection-generated waves in transporting and depositing mechanical energy in the overlying chromospheric and the coronal plasmas"* remains still unanswered (Rosenthal et al., 2002). A recent work by Jefferies et al. (2006) hypothesizes that a viable source of chromospheric-coronal heating may be provided by low-frequency magneto-acoustic waves. Even though these waves are evanescent in higher-than-photospheric layers, it appears they can propagate up to the chromosphere where the magnetic flux is intense and inclined with respect to the gravity vector. The magnetic structures akin to the one displayed in these observations could act as portals for the propagation of this kind of waves.

2. Observations with IBIS

IBIS is bi-dimensional spectrograph installed at the Dunn Solar Telescope (DST) at the National Solar Observatory Sacramento Peak (New Mexico) site. It is essentially composed of a couple of Fabry-Perot interferometers and a set of interferential prefilters. It can be used to scan the spectrum with resolution up to 250000 in the wavelength range 550-850 nm. Recently, IBIS has been upgraded for vector polarimetry analysis. In spectropolarimetric mode, the incoming light to IBIS is modulated by a pair of liquid crystal variable retarders placed in a collimated beam upfront the field stop of the instrument. The light is analyzed by a beam splitter in front of the detector, imaging two orthogonal states onto the same chip thus allowing for dual-beam spectropolarimetry. At each wavelength position six modulation states $I + S$ (and their orthogonal states $I - S$) are acquired with the following temporal scheme: $S = [+Q, +V, -Q, -V, -U, +U]$.

2.1. AR 11005

The observation run was performed in the week between the 13th and 18th of October 2008. We present here some preliminary results from the observation of the 15th, which imaged the Active Region (AR) 11005. The AR11005 as seen by SOHO and Hinode imageries appears as a small bipolar region in the northern hemisphere at high latitude ($\simeq 30°$ N), therefore very likely belonging to the new magnetic cycle. We observed the only structure evident in continuum light, at [25.2° N, 10.0° W]. Such a structure is a sunspot, probably in the decay phase, which exhibits a light-bridge and several umbral-dots. The penumbra of this sunspot, the region where the magnetic field leans towards the photosphere, is not evident in broad-band images, but it shows up in spectropolarimetric measures.

2.2. The dataset

The acquired dataset is particularly rich and complex. The observations were acquired at the DST on October 15, 2008 from 16:34 UT to 17:43 UT. During this period, the adaptive optics was able to correct a variable seeing and provide several high quality scans. The dataset consists of 80 sequences, containing a Full Stokes scan of the FeI 617.3 nm line and I only scan of the CaII 854.2 nm line with 52 seconds cadence, imaging a 50"×80" portion of the Sun. The two spectral lines are sampled with 21 wavelength points each, on equidistant grids of 20 and 40 pm, respectively (see Figure 1). The pixel scale of IBIS images is 0.167", while the integration time was 80 ms. For each narrow-band filtergram, a simultaneous broad-band (621.3 ± 5 nm) counterpart with 0.0835" pixelscale was acquired, imaging the same FOV with the same exposure time. Furthermore, G-band filtergrams (430.5 ± 0.5 nm) with approximately the same FOV, but smaller pixel scale (0.051") were taken simultaneously, but with an exposure time of 15 ms.

2.3. Data calibration and restoring

The pipeline provided by the NSO staff takes care of normal calibration processes (dark frame, flat field, etc.) and also corrects for blue-shift effects (Cavallini, 2006; Reardon & Cavallini, 2008) and instrumental polarization. The ancillary images have been restored with Multi-Frame Blind Deconvolution (MFBD) (von Noort et al., 2005), obtaining a single frame for each scan both for the G-band and the broad-band images. To achieve the highest attainable spatial resolution, the spectropolarimetric images have been registered and destretched onto the MFBD broad-band to counter the seeing effect uncompensated by the AO. This procedure improves the spatial resolution of the entire scans, increasing it to be comparable with single filtergram resolution, in particualr in the central part of the field of view.

3. Preliminary results

After the calibration, we proceeded to a preliminary analysis of the magnetic field and of the wave propagation in the photospheric/chromospheric layers.

3.1. Magnetic Field Vector retrieval

In Figure 2 we show the integrated linearly and circularly polarized components of the incoming radiation associated to the FeI 617.3 nm line. The photon polarization is due to the Zeeman effect for the magnetic field in the solar atmosphere, therefore the circular polarization is associated to the line of sight component of the magnetic field vector, while the linear polarization is associated to the projection of B^2 onto the plane orthogonal to the line of sight.

3.2. Wave maps

We also computed the dopplergrams from both Fe I 617.3 and Ca II 854.2 nm line for the whole dataset, and then the correlation between this two quantities as a function of space and time. In particular, we were interested in the crosscorrelation power associated to 3 minute and 5 minute waves. In Figure 2 we show the values of such correlations averaged over the whole dataset duration. The sunspot, outlined by continuum intensity isophote lines, is evidently a site where 5 minutes acoustic waves are totally absent, while the 3 minutes waves show a strong relation with the features present inside the magnetic structure. One of the aims of our study is a more thorough analysis of the complex coupling between magnetic field and acoustic waves.

3.3. Magneto-acustic waves

Using the analysis presented above, we correlated the 3 minute wave power with the linear

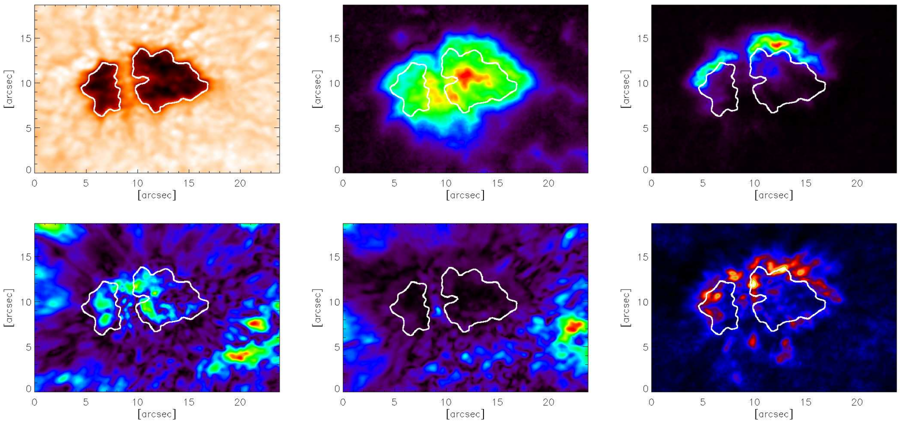

Fig. 2. Upper left panel: the average continuum image at ∼ 617.3 nm with an isophote defining the sunspot contour overplotted. Upper central panel: the integrated circular polarized component of the incoming radiation associated to the FeI 617.3 nm line. Upper right panel: the integrated linear polarized component of the incoming radiation associated to the FeI 617.3 nm line. Lower left panel: Crosscorrelation power in the 3min range. Lower central panel: Crosscorrelation power in the 5min range. Lower right panel: Correlation between the 3 min power and the Fe I 617.3 nm linear polarization signal. On all images the same isophote of the average continuum image is overplotted.

polarization signal from the Fe I 617.3 nm line. It is worth remembering that, in a first approximation, the linear polarization tells us where the magnetic field is inclined with respect to the local gravity vector. In the right panel of Figure 2 we show the value of this correlation averaged over the whole dataset. The sites outlined in this images are candidate sites for Fast Magneto-Acustic waves propagation, because only for such waves it is expected a correlation between pressure variation and magnetic field vector angle.

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